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Coiled Tubing Circular Efficiency: A Systematic Literature Review on Failure Mechanisms, Inspection Methods, and Reuse Potential

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ABSTRACT - Coiled tubing (CT) has become a critical technology in oil and gas operations, yet its service life is constrained by fatigue, corrosion, and erosion. In marginal fields, the high capital cost of new CT strings for permanent installations such as gas lift creates significant economic challenges. Reusing existing CT assets presents a cost-efficient and sustainable alternative. This study conducts a systematic literature review of 33 Scopus-indexed journal and conference publications to examine CT failure mechanisms, integrity inspection methods, and the economic potential of reuse in marginal fields. The reviewed data were classified by failure mode, inspection technique, application, and economic perspective. The findings reveal that low-cycle fatigue is the most extensively studied failure mode, with wall thickness reduction identified as a key indicator of structural degradation. Current integrity assessments rely heavily on predictive modelling and non-destructive evaluation (NDE) methods, particularly magnetic flux leakage (MFL) and eddy current testing (ECT). Nevertheless, the absence of reliable, field-practical wall thickness measurement remains a critical gap, for which ultrasonic testing (UT) emerges as a promising solution. Case studies further demonstrate the technical feasibility and cost-effectiveness of CT reuse. This review underscores the importance of transitioning from a linear "use-and-scrap" paradigm toward a circular "use- inspect-reuse" framework, with UT serving as a pivotal enabler. This approach enhances economic viability and advances alignment with the United Nations Sustainable Development Goals.

Keywords: coiled tubing gas lift, circular economy, coiled tubing integrity, fitness for service, ultrasonic testing.

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INTRODUCTION

Since its introduction in the 1970s, coiled tubing (CT) has become a transformative technology in the oil and gas industry, often regarded as a "game changer" for its efficiency and versatility. As a continuous, flexible conduit fabricated from steel strips, CT can be stored on a large reel, enabling rapid deployment for a wide range of downhole operations and offering significant safety advantages over conventional jointed pipe by minimizing manual handling in harsh environments. Its applications differ: smaller-diameter tubing (typically 1 to 2 inches) is used for workover operations such as sediment cleanouts, perforating, cementing, and stimulation, while larger diameters up to 2.375 inches are employed in coiled tubing drilling (Wiranata et al., 2020). Furthermore, CT is increasingly being used for permanent, long-term installations as part of well completion, such as velocity strings and concentric gas lift systems, highlighting a shift from a consumable intervention tool to a durable, integral component of the production system (Sherik et al., 2019; Subaii et al., 2020).

Despite these advantages, the unique characteristics of CT present significant operational challenges. The manufacturing process, involving welding steel strips into a continuous tube up to 20,000 feet long, creates metallurgical differences between the weld seam and the base metal, creating susceptibility to localized corrosion. The CT string may have either a uniform internal diameter (non-tapered) or a tapered design, where the wall thickness and internal diameter vary along its length to accommodate the immense tensile stresses from its own weight. During every trip into and out the well, the tubing undergoes repeated bending and straightening as it cycles over the gooseneck and reel, inducing severe plastic strain and leading to low-cycle fatigue, a primary factor limiting its service life (Li et al., 2020). These operational stresses, combined with mechanical damage, corrosion, and erosion, can cause premature failure, making accurate life prediction and integrity management critical for both safety and economic viability (Brown et al., 2019).

Coiled tubing failure-contributing factors

To ensure that Coiled tubing (CT) operations are conducted safely and economically, a thorough understanding of the material's failure mechanisms is essential. The service life of a CT string is governed by a combination of mechanical, environmental, and operational factors. Although manufacturing defects were once a major concern, improvements in processing and welding technologies have reduced their prevalence. However, the weld seam and heat-affected zone often exhibit lower corrosion resistance than the base metal, acting as a potential failure initiation site (Yang et al., 2021). Similarly, while surface-level operational factors such as injector gripping forces are managed through established best practices, the complex interplay of fatigue, pressure, and material degradation remains a major challenge.

Fatigue and mechanical stress are arguably the most critical life-limiting factors for CT. During a single trip into and out of the well, the tubing undergoes at least six bending and straightening cycles as it passes over the reel and gooseneck arch. This process induces severe plastic strain, often exceeding 2-3%, which defines the failure mode as low-cycle fatigue. Moreover, high internal pressure significantly worsens this damage by creating circumferential (hoop) and axial stresses that, when combined with bending, accelerate fatigue failure and drastically reduce the number of cycles a string can withstand before fracture (Zhou et al., 2019). Furthermore, operational factors such as reverse bending, caused by improper equipment setup or the absence of a straightener, can expand the strain range and further shorten fatigue life (Wiranata et al., 2020).

In addition to mechanical stresses, the CT is often exposed to harsh downhole environments that cause material degradation through corrosion and erosion. Corrosion is a major contributor to CT failure, responsible for a significant percentage of incidents reported in the field (Brown et al., 2019. It occurs in various forms, including electrochemical reactions in the presence of CO_2 and H_2S, which create a sour environment leading to embrittlement and Sulphide Stress Cracking (SSC), particularly in high-strength steels (Tale et al., 2021). Metallurgical differences between the weld seam and the base material can create a galvanic couple, causing preferential grooving corrosion along the weld, which acts as a stress concentrator and potential crack initiation site (Shaohu et al., 2020). Erosion is the physical removal of material by high-velocity fluids carrying solid particles. It commonly occurs in operations such as hydraulic fracturing, where proppant is pumped at high rates, or in wells producing formation sand. This erosive wear causes localized wall thinning, reducing the tubing's pressure containment and load-bearing capacity, and accelerating both burst and fatigue failures (Shaohu et al., 2021). The combined and often synergistic effects of fatigue, pressure, corrosion, and erosion necessitate life management models and robust inspection programs to ensure the safe and economical reutilization of coiled tubing assets.

Coiled tubing inspection

The integrity management of coiled tubing CT) is critical for ensuring operational safety and economic efficiency. Given the high cost of CT strings and the severe consequences of downhole failure, robust inspection programs are essential (Brown et al., 2019). The primary goal of these inspections is the early identification of service-induced defects such as fatigue cracks, corrosion pitting, mechanical damage, and wall thickness reduction, which can compromise the tubing's structural integrity (Zhou et al., 2019). Accurate assessment of the tubing’s condition enables operators to make informed decisions about maintenance, repair, or retirement, thereby preventing catastrophic failures, minimizing non-productive time (NPT), and safely maximizing the asset's service life. To achieve this, the industry employs several non-destructive testing (NDT) methods to evaluate tubing conditions without causing damage. These methods are chosen for their practicality in field environments and their ability to provide reliable data for life-tracking models. The most commonly used NDT technologies discussed in the literature for CT inspection are magnetic flux leakage (MFL), eddy current testing (ECT), and, to a lesser extent, ultrasonic testing (UT). The resulting data are then integrated into life prediction models to provide a more accurate assessment of the tubing's condition (Zhao et al., 2020; Zhou, Qin, Xie, et al., 2020; Zhou, Zhang, Wang, et al., 2020).

MFL is one of the most widely used methods for inspecting ferromagnetic materials such as CT. The principle involves magnetizing the pipe to a near-saturation state, where any defects, such as cracks or corrosion pits, disrupt the magnetic field, creating "leakage" detectable by sensors. Modern MFL systems can provide a 360° view of the pipe, identifying localized defects and internal features such as bias welds, which are critical for tracking plastic deformation and pipe elongation over its service life (Wiranata et al., 2020). Recent advancements focus on overcoming challenges such as detecting defects without complex rotating magnetization, using high-precision tri-axial fluxgate sensors to analyse magnetic field distortions under non-magnetized conditions (Zhou et al., 2020).

ECT employs electromagnetic induction to find flaws. An alternating current passed through a coil generates a primary magnetic field, which induces circulating eddy currents in the tubing wall. Discontinuities in the material, such as cracks or changes in wall thickness, disturb these currents, and this change is detected by a sensor. ECT is highly effective for detecting surface and near-surface defects. Recent innovations include Pulsed Alternating Current Field Measurement (PACFM), which uses pulse signals to achieve deeper penetration for detecting non-surface defects and quantitatively evaluating wall thickness (Zhao et al., 2020). Other research focuses on developing novel probe designs, such as the circumferential eccentric eddy current probe (ECT), to improve sensitivity and provide both axial and circumferential information about defects in small-diameter tubes (Yang et al., 2021a).

UT uses high-frequency sound waves to provide direct, quantitative measurements of wall thickness and to detect internal flaws. The ultrasonic tool offers advantages including portability, in-situ inspection capability, and real-time measurement (Pudiyarto et al., 2015). While highly accurate, conventional UT has a significant operational disadvantage for CT inspection due to its reliance on a liquid couplant for sound transmission. This requirement is often impractical for high-speed, online field applications, as managing a liquid couplant over thousands of meters of tubing is difficult, and solid couplants can create friction that damages the pipe. Despite this challenge, UT remains a well-established NDT method for CT inspection. Specialized techniques such as Electromagnetic Acoustic Transducers (EMATs), which generate ultrasonic waves without direct contact, present a potential solution to this issue and represent a potential area for further technological advancement.

Coiled tubing gas lift: an opportunity for sustainable reuse

Artificial lift is required to maintain production when declining reservoir pressure is insufficient to sustain natural flow (Amanda et al., 2019; Maurenza et al., 2023). Coiled tubing gas lift (CTGL) has emerged as an innovative and highly effective artificial lift solution, particularly for reviving production in mature or marginal fields where conventional rig-based workovers are economically unviable. The system typically involves running a smaller-diameter CT string inside the existing production tubing to inject gas at a determined depth, thereby reducing hydrostatic pressure and allowing the well to flow. Case studies from Pakistan and Libya have demonstrated the success of this rig-less technique, which has doubled field production rates by bringing dead wells back online without requiring expensive new completion systems or workover rigs. However, the presence of axial and circumferential defects on the CT surface poses a high risk of failure when the CT is used under acidic, high-pressure, and high-temperature wells. As the CT cannot rotate, detecting axial defects using traditional magnetic flux leakage methods is challenging. To address this, the present study proposes a new method based on fluxgate sensor weak magnetic detection technology for detecting arbitrary direction defects under non-magnetized conditions. The proposed method employs tri-axial fluxgate sensors, eliminating the need for complicated designs such as rotating magnetization. A data acquisition system was developed to amplitude and coordinate magnetic anomalies using the magnetic field gradient method. Sample tubes with arbitrary direction defects were tested, and the results show that the method can quickly locate and identify such defects in the CT. The magnetic induction intensity signals obtained from prefabricated arbitrary-direction and circumferential defects show noticeable variations. The measured signal strength also varies significantly at the same lift-off height for different defects. These findings indicate that tri-axial fluxgate detection method effectively addresses the challenges of detecting arbitrary-direction defects. Despite the proven success of CTGL as a long-term solution, a significant operational and economic gap exists in the current lifecycle management of these assets. The prevailing practice is to scrap the CT string after retrieval, even though field evidence often suggests no significant damage. This presents a missed opportunity for material reutilization, which is essential for achieving both economic efficiency and sustainable development goals. Therefore, this review aims to bridge that gap by addressing most contributing factors to coiled tubing failure in CTGL applications and identifying inspection methods that are both suitable and practicable to ensure coiled tubing’s for reuse. By developing a robust inspection protocol and applying direct methods such as ultrasonic testing to verify wall thickness, operators can confidently extend the life of their CT inventory. Such a program would significantly reduce waste, lower capital expenditure on new strings, and advance a circular economy model within the oil and gas industry.

METHODOLOGY

Research design

This study adopts a systematic literature review (SLR) methodology to synthesize and analyze existing research on CT integrity, inspection, and lifecycle management. The review focuses on peer-reviewed articles and conference papers published primarily between 2019 and 2021, encompassing 33 documents. Its objective is to identify key trends, technological advancements, and persistent gaps in the understanding of CT failure and reuse, particularly in the context of extending the material's circular life to enhance both economic and environmental sustainability. The review is structured to answer the following research questions, derived from recurring themes in the provided literature: RQ1: What are the primary factors and mechanisms contributing to coiled tubing failure? RQ2: What are the predominant inspection methods and analytical techniques used to assess CT integrity? RQ3: How do these technical findings relate to the economic and operational viability of coiled tubing applications?

By systematically analysing these interconnected themes, this review aims to consolidate the current state of knowledge and identify the critical gap between the successful long-term deployment of CT and the implementation of robust, data-driven protocols for its reutilization. This synthesis underscores the opportunity to leverage simple and effective inspection technologies to enhance the economic and environmental performance of coiled tubing operations.

Data source

The Scopus database was selected for its comprehensive coverage of engineering and energy-related publications and its credibility as a comprehensive data source. The following Boolean query was applied:

TITLE-ABS-KEY ("coiled tubing" AND "gas lift") OR ("coiled tubing" AND "fatigue") OR ("coiled tubing" AND "lifespan") OR ("coiled tubing" AND ("test" OR "inspection")) AND PUBYEAR > 2018 AND PUBYEAR < 2026 AND (LIMIT-TO (DOCTYPE , "cp") OR LIMIT-TO (DOCTYPE , "ar")) AND (LIMIT-TO (LANGUAGE , "English"))

This query identifies articles discussing "coiled tubing" in relation to "gas lift," "fatigue," "lifespan," and "test" or "inspection." The search is limited to publications from 2019 to 2025 to ensure the inclusion of recent and relevant studies. It is further restricted to conference papers (cp) and articles (ar) written in English.

Results and data analysis

The systematic search yielded 1,411 articles after duplicate removal. Initially, an automation

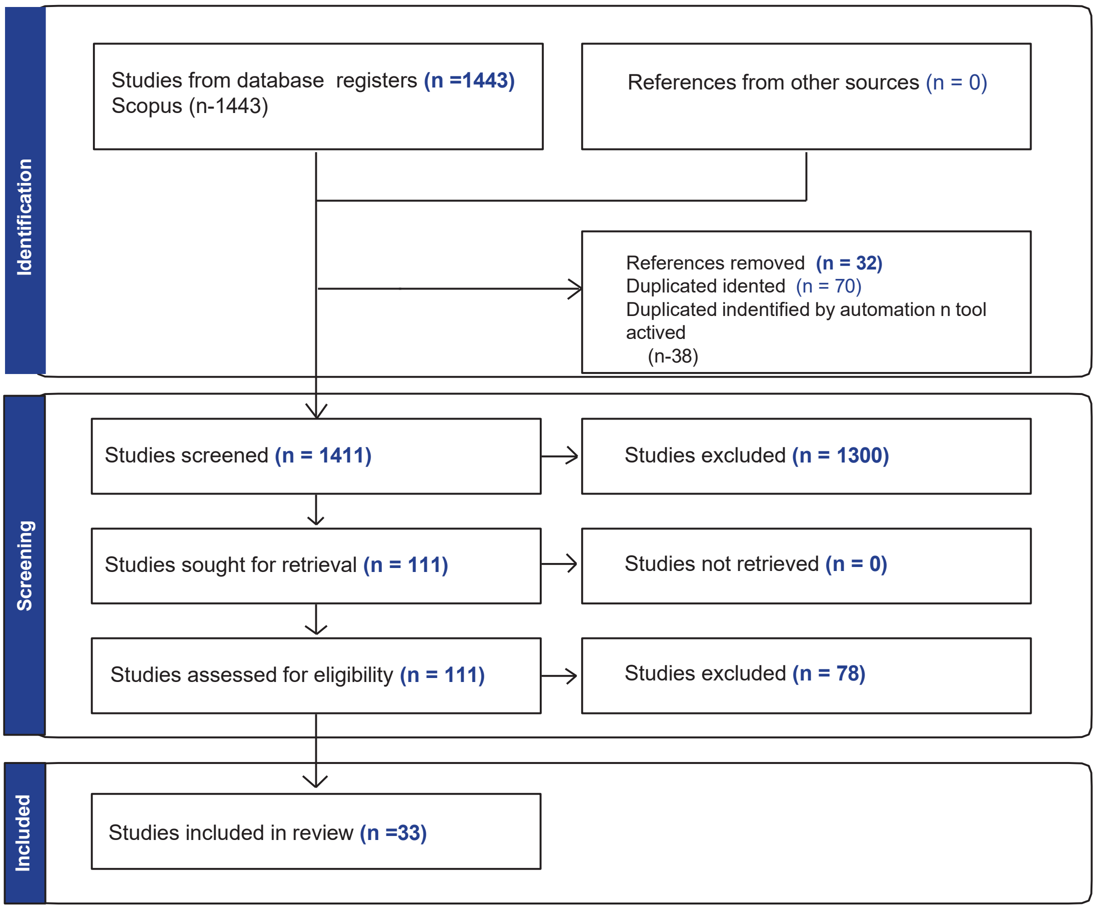

Figure 1. Search result and data screening

tool identified 70 duplicates. Manual identification confirmed 32 as true duplicates, while 38 documents were reinstated. A total of 1,300 documents did not meet requirements or strongly related to the study, leaving 111 articles for full-text review phase. Ultimately, 33 out of 111 articles met the inclusion criteria. A summary of search results and data screening process is illustrated in Figure 1.

RESULT AND DISCUSSION

The final dataset comprises 33 articles analysed across six categories focusing on factors contributing to: 1). Failure mode; 2). Inspection methods; 3). Type of data for testing; 4). Applications of coiled tubing gas lift; 5). Affiliation, and; 6). Economic aspect. To identify relationships between the relevant variables, the analysis was divided into three stages. Category (1) is discussed exclusively to review typical failure factors of coiled tubing and main contribution to certain operation in stage 1. Stage 2 analyses category (2) and (3), which are directly and strongly correlated, together. Similarly, the last three categories (4), (5), and (6) are analysed collectively to provide a comprehensive view of the interrelated factors in stage 3. This structured approach ensures a thorough examination of the data, highlighting key contributing factors and their interconnections, thereby facilitating a deeper understanding of the underlying issues.

Failure mode

The initial analysis highlights the factors contributing to coiled tubing failure. As shown in Figure 2, failure analyses were discussed in 28 out of 33 reviewed papers, focusing on fatigue due to bending cycle, exposure to internal or external operation pressure, corrosion, and erosion. Failure due to mechanical stress, especially from repeated bending and straightening cycles during CT operations, is the most frequently reported failure mechanism. This category includes fatigue, fracture, and other forms of mechanical damage studied in 19 literatures. The primary contributor to failure is low-cycle fatigue (LCF), resulting from plastic deformation that occurs each time the tubing is spooled on and off the reel and over the gooseneck (bending cycle) (Li et al., 2020; Shaohu, Hao, Hong, et al., 2021; Shaohu, Hao, Hui, et al., 2021; Zhao et al., 2020; Zhou et al., 2019. This process accumulates plastic strain, leading to the initiation and propagation of micro-cracks (Li et al., 2020; Shaohu et al., 2021; Tong & Gao, 2019; Zhou et al., 2019. Other mechanical failure modes include helical buckling and plastic elongation, which can cause operational failures in applications such as CT drilling. Operations involving internal or external pressure further exacerbate CT damage, causing fractures in combination with bending cycles (Shaohu, Feng, Xianjin, et al., 2019; Shaohu, Hao, Hong, et al., 2021; Shaohu, Yuandeng, Hao, et al., 2021; Tong & Gao, 2019; Zhao et al., 2020; Zhou et al., 2019.

Corrosion and erosion present a significant threat to CT integrity, particularly in long-term installations or sour environments. Corrosion caused by degrading material was identified as a failure mechanism in 13 articles, while erosion was discussed in 9 papers. The study identifies several forms of corrosion, including pitting corrosion, grooving corrosion at weld seams (Yan et al., 2021, and galvanic corrosion between the weld and base metal (Shaohu et al., 2020. Sour environments containing H_2S can cause premature brittle failure at stress levels far below the material's yield strength, known as SSC (Sulphide Stress Cracking) (Khalid et al., 2020; Subaii et al., 2020; Tale et al., 2021. Erosion and abrasive wear are major concerns in operations involving the pumping of solids, such as hydraulic fracturing with proppants or wellbore cleanouts. Erosion results from high-speed, particle-laden fluids abrading the tubing wall. In fracturing operations, proppants can form a "sliding bed" that causes friction abrasion, particularly on the outer curve (extrados) of the spooled tubing (Jia et al., 2020; Mustaffa et al., 2021; Zhang et al., 2021. This leads to the formation of defects such as pits and scratches and causes a general reduction in wall thickness. The combined effect of erosion and corrosion can create surface damage that accelerates fatigue (Mao

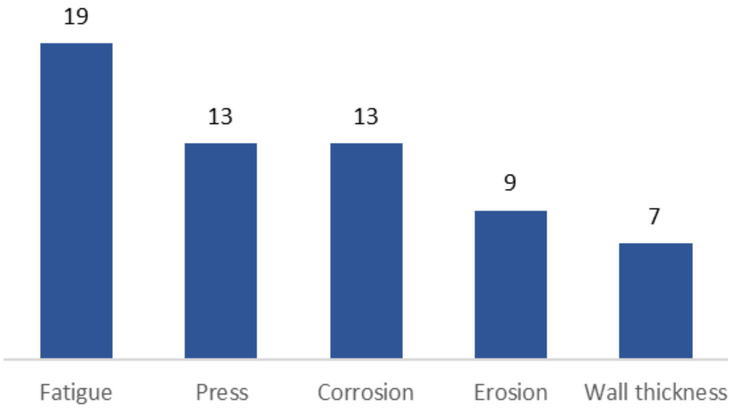

Figure 2. Failure contributing factors of coiled tubing

et al., 2020). Further review of the studies discussed that wall thickness reduction is a critical *effect* of mechanisms such as erosion, corrosion, and the plastic deformation associated with fatigue (Zhou et al., 2019. Wall thickness serves as a visible parameter for assessing the remaining life and integrity of CT, as highlighted in 7 articles. Erosion alone can significantly affect wall thickness degradation (Jia et al., 2020. Due to complex operational parameters, wall thinning results from a combination of several CT failure mechanisms. Combination of operational fatigue and pressure appears as the cause of wall thinning due to elongation (Mohammadi et al., 2019). Abrasive materials causing erosion, in conjunction with operational fatigue or pressure led to wall thinning (Jia et al., 2020; Mustaffa et al., 2021; Shaohu et al., 2019. Corrosive environments combined with operational fatigue or pressure also result in wall thickness reduction (Zhang et al., 2021; Zhao et al., 2020).

This previous study demonstrates that multiple failure factors provide a holistic understanding of coiled tubing failures by examining the interplay between wall thickness, corrosion, erosion, and operational parameters. The ultimate goal of identifying wall thickness is to use this data to make informed predictions about the CT's remaining life and fitness for service.

Inspection methods and type of data

An analysis of the testing methods used across the surveyed literature reveals a strong trend towards simulation to predict failure, with physical inspections employed to collect essential data for model validation and field data used for real-time assessment, as shown in Figure 3. Finite element analysis (FEA/FEM) is the most frequently used simulation technique to model the complex stress and strain states that lead to fatigue. By simulating bending cycles and pressure loads, FEA can predict plastic strain accumulation, which causes fatigue failure and is also linked to wall thinning and diameter growth (Long et al., 2021; Shaohu et al., 2019; Shaohu, Hao, Hong, et al., 2021; Shaohu, Hao, Hui, et al., 2021; Yang et al., 2021; Zhao et al., 2020; Zhou et al., 2020). Computational fluid dynamics (CFD) is specifically used to predict wall thickness reduction due to erosion. CFD identifies areas of high impact and calculates erosion rates, which are then converted into direct measures of wall loss over time (Jia et al., 2020; Mohammadi et al., 2019; Zhang et al., 2021. Researchers have also developed analytical models based on theoretical approaches to calculate performance limits, such as tubing collapse pressure. Probabilistic models employ statistical methods, such as Monte Carlo Simulations, to assess the probability of burst failure by incorporating predicted wall loss from

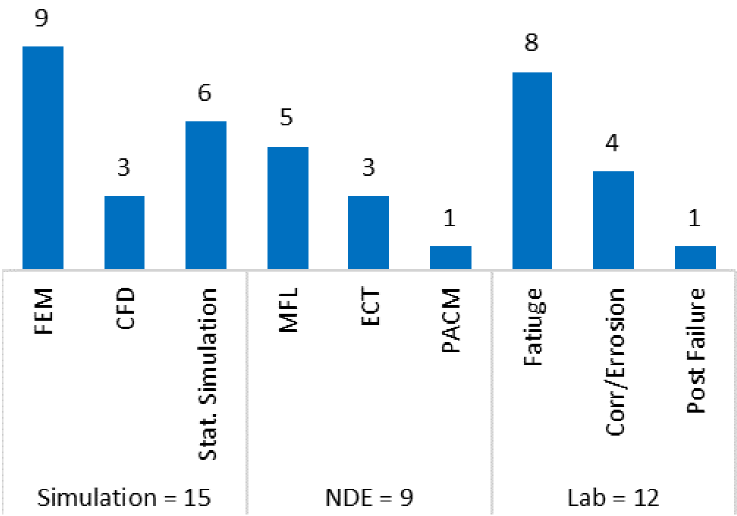

Figure 3. Inspection method used for failure early detection

erosion models. The second inspection method involves NDT using direct data field measurements. Among the physical NDT methods discussed, electromagnetic techniques are the most prominent, particularly MFL. MFL is used to detect localized defects and changes in wall thickness. It can also measure the distance between bias welds to provide a direct field measurement of plastic elongation, a key indicator of accumulated strain (Wiranata et al., 2020). Advanced applications of MFL, such as those using tri-axial fluxgate sensors, are being explored to detect defects in any orientation without requiring complex magnetization procedures (Long et al., 2021; Vera et al., 2020; Wiranata et al., 2020; Zhou et al., 2020). ECT, which uses electromagnetic induction to identify flaws by detecting changes in the flow of induced eddy currents within the tubing wall, is effective for detecting surface defects, measuring changes in diameter and ovality, and evaluating microstructures consistency at the critical bias weld zone (Yang et al., 2021; Zhou et al., 2020; Zhou et al., 2019). The reviewed papers showcase innovations in this area, including the development of Pulsed Alternating Current Field Measurement (PACFM) for quantitative wall thickness evaluation (Zhao et al., 2020).

The last testing method identified in the reviewed literature is laboratory experimentation, discussed in 12 articles (Figure 6). Laboratory testing serves three purposes: fatigue testing, corrosion/erosion testing, and failure analysis. Fatigue testing uses full-scale fatigue testers replicate field conditions and generate direct data on the number of cycles to failure for calibrating fatigue models (Mohammadi et al., 2019; Shaohu, Feng et al., 2019; Shaohu et al., 2021; Shaohu et al., 2021; Zhao et al., 2019). Corrosion and erosion testing involves laboratory setups that simulate down-hole environments to measure corrosion rates and wear mechanisms, providing critical data on how these processes contribute to wall degradation (Mao et al., 2020; Shaohu et al., 2020; Tale et al., 2021; Yan et al., 2021. While failure analysis involves investigating the root cause of failure (Mao et al., 2020).

Notably, UT is not a primary focus in any of the 33 papers reviewed, despite its accuracy in measuring wall thickness. This omission is likely due to the practical challenges of using conventional UT in the field, particularly the requirement for a liquid couplant, which is difficult to apply consistently during high-speed, online inspections (Zhao et al., 2020). While electromagnetic methods such as MFL and ECT are well-established for online inspection, they provide an indirect measurement of wall thickness by inferring it from changes in magnetic or electrical properties. Simulation models are predictive and require validation, while laboratory methods are destructive and unsuitable for coiled tubing application.

In summary, while the reviewed literature emphasises the development and refinement of electromagnetic inspection techniques such as MFL and ECT, it simultaneously reveals a potential gap and opportunity in the application of Ultrasonic Testing (UT). However, given that UT is a recognized NDT method for CT (Zhou et al., 2020) and that accurate wall thickness data is critical for reliable fatigue life prediction (Zhou et al., 2019), the value of this direct measurement technique should not be underestimated. Future development, particularly in non-contact methods such as Electromagnetic Acoustic Transducers (EMATs), could bridge the gap between complex computational models and the practical need for a low-cost, reliable, and straightforward inspection tool. Advancing UT for real-time field measurements represents a significant opportunity to improve the safety and economic viability of coiled tubing lifecycle management.

Type of applications, affiliation, and economical aspect

An analysis of the applications and affiliations presented in the literature reveals a clear link between the practical use of coiled tubing (CT) and its economic viability. The decision to use, reuse, or retire a CT string is fundamentally an economic consideration, balancing the asset's cost against the risk and consequence of failure. The reviewed studies provide significant insight into this dynamic, particularly in distinguishing between short-term service applications such as workover or drilling and long-term permanent installations. This section aims to address RQ3 by examining the relationship between technical findings and the economic and operational viability of coiled tubing applications, as illustrated in Figure 4.

The 33 reviewed articles on coiled tubing applications can be categorized into two groups: temporary well intervention services and permanent installations. These two categories involve different stakeholders and have distinct operational and economic considerations. The literature focuses on CT used for temporary well interventions such as workover or drilling operation to service wells. These high-intensity, short-duration activities include hydraulic fracturing, milling bridge plugs, wellbore cleanouts, and drilling. Such applications involve numerous bending cycles, making low-cycle fatigue the dominant concern (Li et al., 2020; Shaohu et al., 2019; Shaohu, Hao, Hong, et al., 2021; Shaohu, Hao, Hui, et al., 2021; Shaohu, Yuandeng, Hao, et al., 2021; Zhao, Zhong, Feng, et al., 2020; Zhou , Tan, Wan, et al., 2019. Research in this area, often conducted by service companies and academic institutions, heavily focuses on predicting and managing fatigue life to ensure CT reliability throughout a single job or an entire campaign (Brown et al., 2019a; Jia et al., 2020; Varma et al., 2019; Vera et al., 2020; Wiranata et al., 2020; Zhao et al., 2019; Zhou et al., 2020.

Permanent Installations such as CTGL and Velocity Strings are discussed in four papers addressing the use of CT for permanent or semi-permanent installations that may last for years. The primary examples are CTGL (Khalid et al., 2020; Moffat, 2020; Sherik et al., 2019 and VS (Subaii et al., 2020. In these applications, the CT is installed in the well and remains static for a long period, with minimal fatigue cycles (often just one trip in). Instead, the primary integrity concerns shift to long-term material degradation, such as corrosion and sulfide stress cracking (SSC), especially in sour environments. This research is often driven by operators in collaboration with service companies, aiming to develop cost-effective solutions to revive production from mature or non-producing wells.

Affiliation statistic, as shown in Figure 5, illustrates the different priorities across industry sectors. Academic and research institutions primarily focus on fundamental scientific and engineering challenges. Their work involves developing new theoretical models for fatigue and fracture, creating advanced simulation techniques such as FEA (Long et al., 2021; Shaohu et al., 2019; Shaohu, Hao, Hong, et al., 2021; Shaohu, Hao, Hui, et al., 2021; Yang et al., 2021b; Zhao et

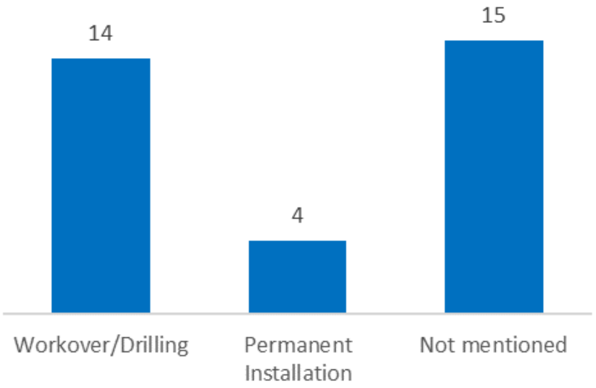

Figure 4. Application of coiled tubing

al., 2020; Zhou et al., 2020, CFD, and designing novel NDE sensors and methods (Jia et al., 2020; Mohammadi et al., 2019; Zhang et al., 2021. Service companies (e.g., Schlumberger, Halliburton, Weatherford) tend to publish case studies demonstrating successful application of their specific technologies and operational procedures. Their focus lies in demonstrating the efficiency, reliability, and economic value of their services, whether through new real-time monitoring system, CTGL installation, or NDE tool for elongation tracking to provide best customer service (Khalid et al., 2020; Moffat, 2020; Subaii et al., 2020; Wiranata et al., 2020. Operators (e.g., Saudi Aramco, Cairn Oil & Gas, Mellitah Oil & Gas), often publishing jointly with service companies, focus on the practical application of CT technology to solve specific field-level problems, such as reviving inactive wells or improving production efficiency. Their primary concern lies in maximizing economic return and operational success of the project (Sherik et al., 2019; Subaii et al., 2020; Varma et al., 2019; Vera et al., 2020).

The discussion of economic aspects is unevenly distributed across these applications, with explicit consideration found in 15 articles. It is most prominent in studies authored by or in collaboration with service providers and oil and gas operators. The economic aspect is often framed around the high cost of failure and inefficiency. A single CT string can cost over $250,000, and failures lead to significant NPT (Brown et al., 2019). The use of CT for permanent installations, such as velocity strings and CGL systems, explicitly presented as a cost-effective solution for extending the life of marginal wells and avoiding expensive workover. Similarly, studies on workover and well intervention highlight the economic benefits of advanced real-time monitoring and modelling in reducing NPT, preventing costly equipment failures, and optimizing resource usage.

Inaccurate life prediction leads to the premature scrapping of valuable assets or unexpected downhole failures. The case for reusing CT is particularly compelling for marginal fields, which rely on artificial lift to remain productive but operate under tight economic constraints, where the high capital cost of a workover or a new dedicated CT string for a gas lift system is significant (Chmelko & Margetin 2020; Zhou et al., 2019). While not a primary focus in the reviewed articles, extending CT life through reutilization offers significant environmental and economic benefits by reducing waste. Instead of being scrapped, these structurally sound CT assets could be repurposed for permanent installations. This practice aligns with a circular economy model, reducing the industrial waste associated with disposing of thousands of feet of steel and minimizing the environmental footprint and energy consumption required to manufacture new strings. This waste is transformed into a valuable asset, improving the overall economics of oil and gas production (Shaohu et al., 2021. The literature highlights that CT integrity management is not just a safety issue but also a critical driver of financial performance. This analysis reveals a critical research gap. While individual applications demonstrate clear economic benefits, a holistic economic review for marginal oilfield development, where sustained business is most impacted by marginal economics and low reserves, is largely absent. The reviewed literature strongly supports the use of CT for secondary recovery in such fields, particularly through permanent installations designed as cost-effective alternatives to more expensive conventional methods (Sherik et al., 2019. The successful retrieval of a velocity string after three years of service with no significant damage further proves the technical feasibility of long-term asset utilization (Subaii et al., 2020. However, the economic analysis in these papers are limited to the initial installation. A comprehensive framework assessing the full lifecycle cost, including inspection, recertification, and reuse of retrieved assets is necessary to align CT operations with sustainable development programs and maximize economic recovery from marginal fields.

Discussion: the opportunity for coiled tubing reutilization in marginal oilfields

In marginal fields and increasingly complex operations, economic viability is paramount. This systematic literature review identifies a significant, yet underexplored opportunity in the oil and gas industry: the formal reutilization of coiled tubing (CT) to extend its lifecycle. While the literature extensively covers failure prediction and prevention, it largely omits the framework for post-retrieval assessment and reuse. This gap is critical, particularly for marginal oilfields, where lean operations and sustained business resilience are essential. Adopting a circular economy model for CT assets, supported by robust inspection and data-driven decision-making, can deliver substantial economic benefits while aligning with the industry with sustainable development goals. The economic case for reusing CT is most compelling in marginal fields, which are characterized by low reserves and tight economic margins. Case studies of permanent CT installations for gas lift and velocity strings demonstrate that these rig-less solutions are highly cost-effective, often enabling production from wells that would otherwise be shut-in. The successful retrieval of a velocity string after three years of service in a sour well, with no significant integrity issues, proves that CT can maintain its structural integrity over long service periods, making it a prime candidate for reuse in less demanding, static applications. Implementing a reuse program would allow operators to significantly reduce the high capital expenditure associated with new CT strings, often exceeding $250,000 each, thereby improving project economics and enhancing long-term business resilience (Brown et al., 2019).

Bridging the gap from a single-use model to a circular one requires addressing the technical findings in this review. The literature establishes that key failure modes such as fatigue, corrosion, and erosion are fundamentally linked to the degradation of the tube's physical properties, particularly wall thickness (Zhang et al., 2021). A robust inspection method is therefore critical for lifecycle extension. The review reveals a significant research gap: while electromagnetic methods such as MFL and ECT are established for online inspection, they provide only indirect measurements of wall thickness, inferred from changes in magnetic or electrical properties. Simulation models are predictive but require validation, while laboratory methods are

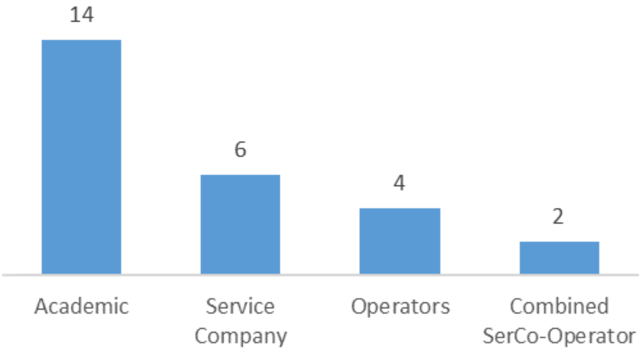

Figure 5. Author's affiliation

destructive and unsuitable for in-service monitoring. This review identifies an opportunity to leverage UT as a practical, low-cost, and reliable method for post-retrieval inspection, providing direct, quantitative wall thickness data to certify a string's fitness for a secondary service life. Establishing a robust framework for CT reutilization directly supports global sustainable development programs. Transitioning from a linear "use and scrap" model to a circular "use, inspect, and reuse" approach offers significant environmental benefits. It reduces steel waste, conserves the energy and resources required to manufacture new tubing, and lowers the overall carbon footprint of oil and gas operations. Extending the lifecycle of coiled tubing is not only an economic opportunity but also a necessary step towards a more sustainable and resilient energy future.

This systematic literature review consolidates findings from 33 studies on coiled tubing (CT) failure, inspection, and application, revealing a research landscape rich in technical analysis but with a significant gap in lifecycle management. In response to RQ1, the literature details primary failure mechanisms, with mechanical fatigue from bending cycles being the most studied, followed by corrosion, erosion, and pressure-related failures (Mohammadi et al., 2019; Shaohu et al., 2021; Yang et al., 2021). Regarding RQ2, the predominant inspection methods combine predictive modelling with field-deployable electromagnetic NDE, such as MFL and ECT, used to predict a string's remaining service life (Shaohu et al., 2020). For RQ3, a crucial finding is that while CT is successfully used in long-term installations such as gas lift and can be retrieved in excellent condition after years of service, economic analyses rarely extend beyond justifying the initial project cost, overlooking the potential value of reutilizing retrieved assets.

This review highlights an opportunity for the industry to evolve its perspective on coiled tubing from a consumable asset, whose failure must be predicted, to a durable asset with an optimizable lifecycle. Future research should focus on developing a holistic economic model that quantifies the full lifecycle value of a CT reuse program, weighing inspection costs against the substantial capital savings from reduced procurement. Field trials are needed to validate the performance and reliability of second-life CT strings, alongside further research on long-term material degradation in static down-hole environments. By adopting a "use, inspect, reuse" model, the industry can move beyond simple failure prevention to a circular economy for coiled tubing, improving project economics in marginal fields and advancing sustainable development goals.

CONCLUSION

The key finding of this review is the recognition of a critical gap in both the literature and current operational practices: the absence of a formal framework for extending the lifecycle of coiled tubing through reutilization. Existing research predominantly focuses on predicting and preventing failure during the primary service life of a string, with little attention to secondary use. This gap presents a significant opportunity, particularly in marginal oilfields where operational efficiency and business resilience are crucial. Transitioning from a linear "use-and-discard" paradigm toward a circular "use–inspect–reuse" model, supported by robust inspection protocols and data-driven decision-making, is therefore essential.

Bridging this gap has considerable implications. For operators, it enables a model where used CT strings are regarded as valuable assets rather than a waste. A string that has reached its fatigue threshold in high-stress applications may remain suitable for long-term static installations, such as CT gas lift systems, thereby reducing capital expenditure for marginal well recovery. For service and technology providers, it creates opportunities for inspection, certification, and redeployment services. For the industry, it promotes a more sustainable model that minimizes steel waste and conserves the resources required for manufacturing new assets. Academic contributions have primarily emphasized the mechanics of failure and the advancement of predictive modeling, while service companies report case studies demonstrating proprietary technology application. Operatordriven studies emphasize economic outcomes of specific projects. This segmentation highlights the identified gap: although each stakeholder addresses a part of the value chain, a comprehensive, end-to-end perspective on the coiled tubing lifecycle remains largely absent.

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GLOSSARY OF TERM

Symbol	Definition	Unit
CTGL	Coiled Tubing Gas Lift	
ECT	Eddy Current Testing	
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FEA	Finite Element Analysis	
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LFC	Low Fatigue Cycle	
MFL	Magnetic Flux Leakage	
NDE	Non-Destructive Evaluation	
PACM	Pulse Alternating Current Field Measurement	

REFERENCES

Brown, P., Gunby, B., & Torres, C. (2019a). An analysis of coiled tubing performance. Society of Petroleum Engineers - SPE/ICoTA Well Intervention Conference and Exhibition 2019, March, 26–27. https://doi.org/10.2118/194306-ms.

Brown, P., Gunby, B., & Torres, C. (2019b). An Analysis of Coiled Tubing Performance. SPE/ICoTA Well Intervention Conference and Exhibition, https://doi.org/10.2118/194306-MS.

Chmelko, V., & Margetin, M. (2020). The performance of selected multiaxial criteria under tension/torsion loading conditions. International Journal of Fatigue, 135, 105532. https://doi.org/10.1016/j.ijfatigue.2020.105532.

Effa D., Amanda, H.T., Ronaldo, N.D. Wijoyo, Chandra, S., & A.A., Prasandi. (2019). Progressing Cavity Pump as A Solution to Increase Productivity of Highly Viscous Oil Wells with Sand Production: A Case Study Of Field X. Scientific Contributions Oil and Gas, 42(3), 115–118. https://doi.org/10.29017/SCOG.42.3.376.

Jia, P., Zhu, X., Xue, S., & Fang, J. (2020). Numerical Simulation on Coiled Tubing Erosion During Hydraulic Fracturing. Journal of Failure Analysis and Prevention, 20(6), 1928–1938. https://doi.org/10.1007/s11668-020-01006-5.

Khalid, A., Molero, N., Hassan, G., Lovie, E., & Khan, R. S. A. (2020, January 15). Coiled Tubing Gas Lift: An Innovative Solution for Reviving Dead Wells in Southern Pakistan. International Petroleum Technology Conference. International Petroleum Technology Conference, Dhahran, Kingdom of Saudi Arabia. https://doi.org/10.2118/19930-MS.

Li, N., Zhu, L. X., Cong, S., & Feng, Y. R. (2020). Fracture Failure Analysis of Φ50.8mm Coiled Tubing. Materials Science Forum, 993, 1235–1241. https://doi.org/10.4028/www.scientific.net/MSF.993.1235.

Long, Y., Huang, S., Peng, L., Wang, S., & Zhao, W. (2021). A Novel Compensation Method of Probe Gesture for Magnetic Flux Leakage Testing. IEEE Sensors Journal, 21(9), 10854–10863. https://doi.org/10.1109/JSEN.2021.3059899.

Mao, L., Cai, M., Liu, Q., & Wang, G. (2020). Influence of oil-water ratio on the wear of Cr13 casing lubricated with drilling fluid. Materials Today Communications, 25, 101341. https://doi.org/10.1016/j.mtcomm.2020.101341.

Maurenza, F., Yasutra, A., & Tungkup, I. L. (2023). Production Forecasting Using Arps Decline Curve Model With The Effect Of Artificial Lift Installation. Scientific Contributions Oil and

Gas, 46(1), 9–18. https://doi.org/10.29017/SCOG.46.1.1310.

Moffat, A. G. (2020). Concentric Gas Lift System Development and Installation in the UK North Sea. SPE/ICoTA Well Intervention Conference and Exhibition, D011S001R003. https://doi.org/10.2118/199827-MS.

Mohammadi, M., Abadeh, A., Nemati-Farouji, R., & Passandideh-Fard, M. (2019). An optimization of heat transfer of nanofluid flow in a helically coiled pipe using Taguchi method. Journal of Thermal Analysis and Calorimetry, 138(2), 1779–1792. https://doi.org/10.1007/s10973-019-08167-y.

Mustaffa, Z., Halim, A. H. A., Kim, D. K., & Van Gelder, P. H. A. J. M. (2021). Reliability assessment of the vertical well system subjected to erosion and tubing failure. Ships and Offshore Structures, 16(2), 127–134. https://doi.org/10.1080/17445302.2019.1710929.

Pudiyarto, S., & Widiyanto, G., & Suryono (2015). Pengembangan Teknologi Ultrasonografi Untuk Aplikasi Bidang Migas (Rekayasa Alat Inspeksi Sumur). Scientific Contributions Oil and Gas, 49(3), 3-6. https://doi.org/10.29017/LPMGB.49.3.1199.

Shaohu, L., Feng, G., Xianjin, W., Hui, X., Zhen, W., & Ting, Y. (2019). Theoretical and experimental research of bearing capacity and fatigue life for coiled tubing under internal pressure. Engineering Failure Analysis, 104, 1133–1142. https://doi.org/10.1016/j.engfailanal.2019.06.062.

Shaohu, L., Hao, Z., Hong, Z., Yang, L., & Zhen, W. (2021). Experimental and numerical simulation study on fatigue life of coiled tubing with typical defects. Journal of Petroleum Science and Engineering, 198, 108212. https://doi.org/10.1016/j.petrol.2020.108212.

Shaohu, L., Hao, Z., Hui, X., & Quanquan, G. (2021). A new theoretical model of low cycle fatigue life for coiled tubing under coupling load. Engineering Failure Analysis, 124, 105365. https://doi.org/10.1016/j.engfailanal.2021.105365.

Shaohu, L., Yuandeng, W., & Hao, Z. (2021). Critical Ultimate Load and Ultimate Bearing Failure of CT110 with Initial Crack Defect. Journal of Failure Analysis and Prevention, 21 (1), 204–212. https://doi.org/10.1007/s11668-020-01047-w.

Shaohu, L., Yuanliang, L., & Hong, Z. (2020). Corrosion Failure and Electrochemical Corrosion Behavior of Coiled Tubing. Journal of Failure Analysis and Prevention, 20(6), 1964–1974. https://doi.org/10.1007/s11668-020-01007-4.

Sherik, A., Abdalla, M. Ben, Abdoalqader, A., Abusninah, G., Abdaldaem, A. A., & Ayad, A. N. Ben. (2019). Coiled-tubing gas lift system doubled oil production from al-wafa field. Society of Petroleum Engineers - SPE Kuwait Oil and Gas Show and Conference 2019, KOGS 2019. https://doi.org/10.2118/198096-MS.

Subaii, A., Al Ghubayni, M. R., Shawli, Y., Sunagatov, R., Ahmed, D., Arifin, M., Pochetnyy, V., & Santali, M. (2020). Successful Retrieval of First Installed Velocity String – A Case Study from Middle East. SPE/ICoTA Well Intervention Conference and Exhibition, D011S001R001. https://doi.org/10.2118/199837-MS.

Tale, S., Ahmed, R., Elgaddafi, R., & Teodoriu, C. (2021). Sulfide Stress Cracking of C-110 Steel in a Sour Environment. Corrosion and Materials Degradation, 2(3), 376–396. https://doi.org/10.3390/cmd2030020.

Tong, S., & Gao, D. (2019). Elastic-plastic collapse limit analysis of coiled tubing under complex stress state. Journal of Petroleum Science and Engineering, 174, 106–114. https://doi.org/10.1016/j.petrol.2018.11.018.

Varma, N., Nagar, A., Manish, K., Srivastav, P., Nekkanti, S., Bohra, A., & Srivastav, P. (2019). Prosper & Cerberus Modelling for Efficient WBCOs in Artificial Lift Flowing Wells. SPE Oil and Gas India Conference and Exhibition, D021S011R003. https://doi.org/10.2118/194687-MS.

Vera, V., Torres, C., & Higuera, J. (2020). Real-Time Hybrid Coiled Tubing Technology: A Review of Challenges and Opportunities in Field Operations. SPE/ICoTA Well Intervention Conference and Exhibition, D022S019R001. https://doi.org/10.2118/199840-MS.

Wiranata, K., Ridene, A., Yusoff, M. N. A. M., Hamdi, A., Sa, R., Chaari, Y., & Arifin, M. (2020). Novel application of magnetic flux leakage-based technology validating pipe elongation in coiled tubing drilling operation. International Petroleum Technology Conference 2020, IPTC 2020. https://doi.org/10.2523/iptc-20084-ms.

Yan, F., Li, Z., Zhang, C., & Wang, H. (2021). Study on grooving corrosion behavior of QT800 coiled tubing. AIP Advances, 11(4), 045013. https://doi.org/10.1063/5.0044098.

Yang, Q., Xie, S., He, K., Chen, Y. E., Chen, Z., Uchimoto, T., & Takagi, T. (2021a). A novel circumferential eccentric eddy current probe and its application for defect detection of small-diameter tubes. Sensors and Actuators A: Physical, 331, 113023. https://doi.org/10.1016/j.sna.2021.113023.

Yang, Q., Xie, S., He, K., Chen, Y.-E., Chen, Z., Uchimoto, T., & Takagi, T. (2021b). A novel circumferential eccentric eddy current probe and its application for defect detection of small-diameter tubes. Sensors and Actuators A: Physical, 331, 113023. https://doi.org/10.1016/j.sna.2021.113023.

Zhang, Y., Luo, Q., Wang, H., Gong, X., & Guo, L.-L. (2021). Residual Life Study of Coiled Tubing for Erosion Wear. Journal of Failure Analysis and Prevention, 21(1), 320–328. https://doi.org/10.1007/s11668-020-01065-8

Zhao, G., Li, J., Zhang, Y. X., Zhong, J., Liang, Z., & Xiao, S. (2019). A study on ductile fracture of coiled tubing based on cohesive zone model. Engineering Fracture Mechanics, 209, 260–273. https://doi.org/10.1016/j.engfracmech.2019.01.027.

Zhao, G., Zhong, J., Feng, C., & Liang, Z. (2020). Simulation of ultra-low cycle fatigue cracking of coiled tubing steel based on cohesive zone model. Engineering Fracture Mechanics, 235, 107201. https://doi.org/10.1016/j.engfracmech.2020.107201.

Zhao, J., Li, W., Ge, J., Yuan, X., Yin, X., Zhu, Y., Wang, Z., Liu, Y., & Li, J. (2020). Coiled Tubing Wall Thickness Evaluation System Using Pulsed Alternating Current Field Measurement Technique. IEEE Sensors Journal, 20(18), 10495–10501. https://doi.org/10.1109/JSEN.2020.2993028.

Zhou, Z. M., Tan, J. S., Wan, F., & Peng, B. (2019). Improvement and determination of the influencing factors of coiled tubing fatigue life prediction. Advances in Mechanical Engineering, 11(9), 1–9. https://doi.org/10.1177/1687814019880131.

Zhou, Z., Qin, M., Xie, Y., Tan, J., & Bao, H. (2020). Experimental Study of Microstructures in Bias Weld of Coiled Tubing Steel Strip With Multi-Frequency Eddy Current Testing. IEEE Access, 8, 48241–48251. https://doi.org/10.1109/ACCESS.2020.2979414.

Zhou, Z., Zhang, J., Wang, C., Wan, F., He, S., & Yu, R. (2020). Non-Magnetization Detection of Arbitrary Direction Defects in Coiled Tubing Based on Fluxgate Sensor. IEEE Sensors Journal, 20(14), 7661–7668. https://doi.org/10.1109/JSEN.2020.2979497.
(Wiranata et al., 2020).